# Improvements to the CALIOP Surface Detection Algorithm

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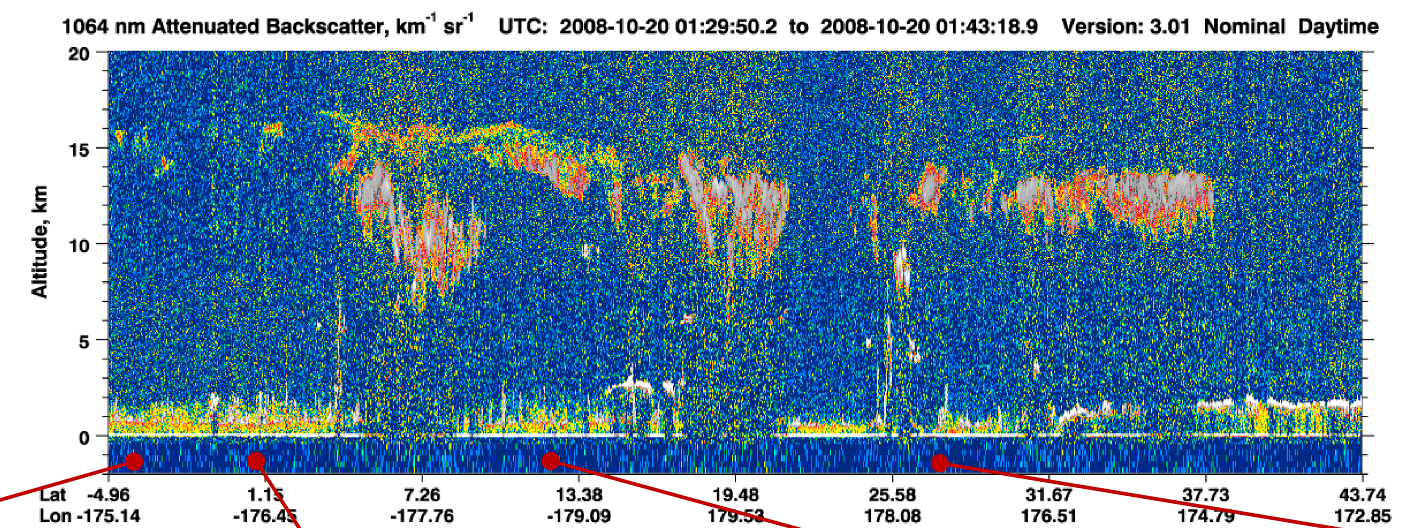
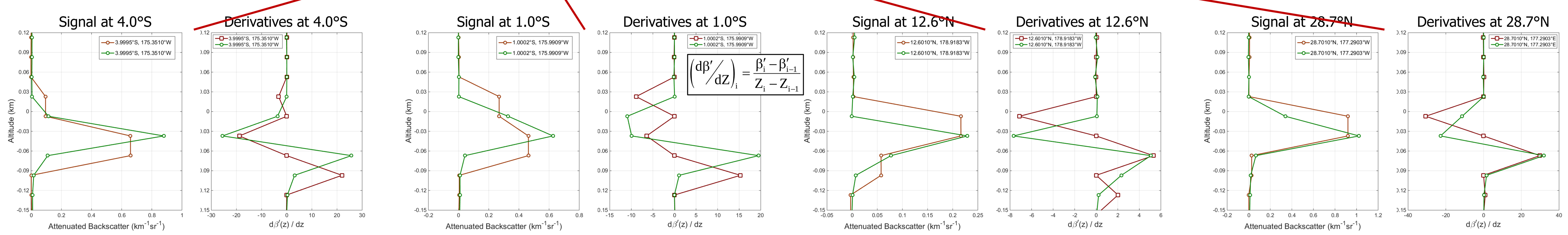
## Surface Returns At Single-Shot Resolution

At 532 nm, backscatter from the Earth's surface is spread over three contiguous range bins, with the peak signal occurring in either the first (uppermost) or second of these bins. Because the 1064 nm data is averaged to 60-m on-board, the 1064 nm can extend over 4 bins

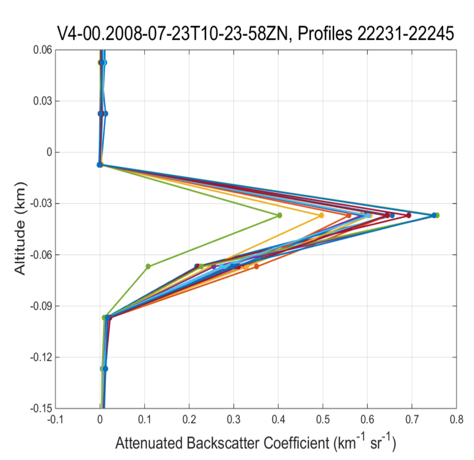


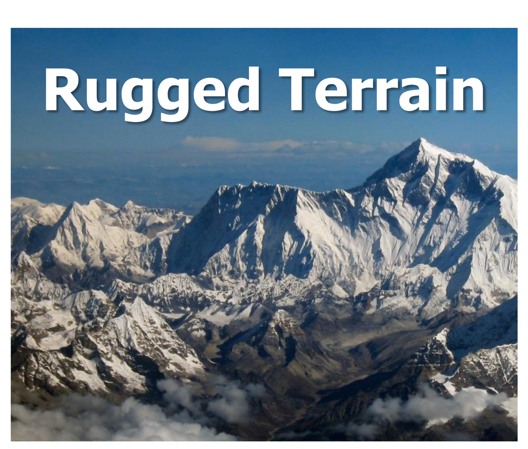

As shown in the line plots below, we take advantage of the consistent geometry of the surface returns by using a derivative test to locate the onset of the surface signal. Derivatives are computed using a two-point backward differences applied to the attenuated backscatter coefficients.

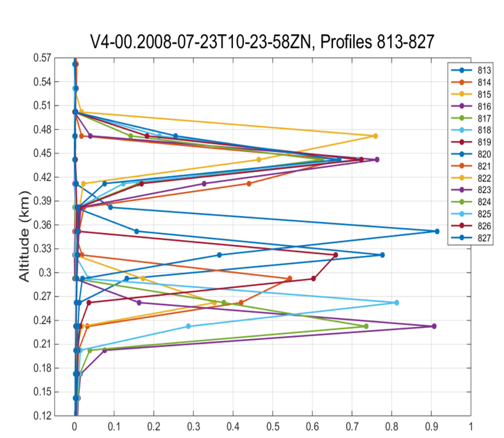



## Surface Returns in Multi-Shot Averages

Depending on the terrain, multi-shot averaging can smear the discrete single shot surface return over multiple range bins that may not always be contiguous, and thus a different detection scheme is require

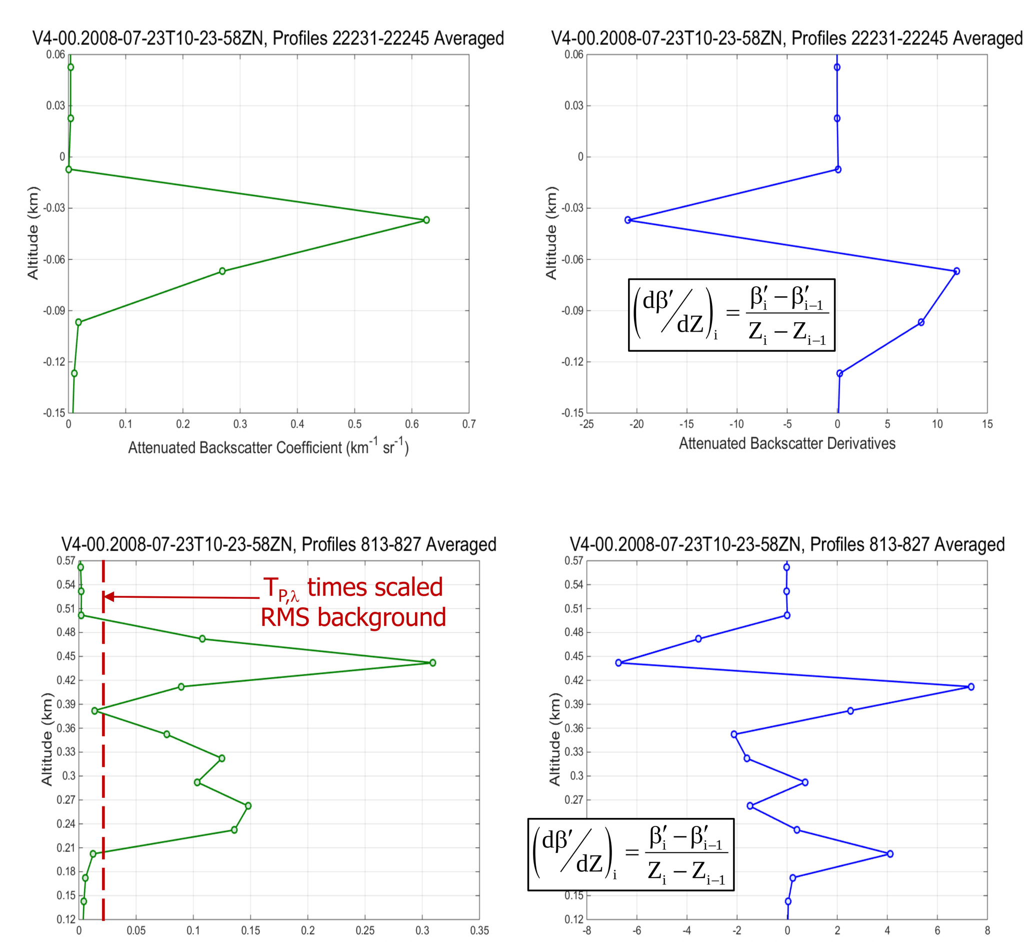




### Procedure

a) Use single-shot detection results to define a vertical surface search region
b) Compute the scaled RMS background signal
c) If over ocean, locate surface return using the derivative technique
d) Otherwise, define surface top as the first (i.e., highest) point in the search region for which the attenuated backscatter coefficient exceeds $T_{P,\lambda}$ times the scaled RMS background. The surface extent is defined by the last (lowest) point that exceeds this threshold.




## V4 Surface Detection Procedure

a) Use a digital elevation map (DEM) to define a vertical surface search region
b) Compute the scaled RMS background signal (i.e., convert the background signal into a pseudo-attenuated backscatter coefficient)
c) Compute derivatives of the attenuated backscatter profiles in the surface search region
d) Determine minimum and maximum derivatives and peak signal value in the search region
e) Apply tests to both the signal and the derivatives to see if the surface return can be reliably detected

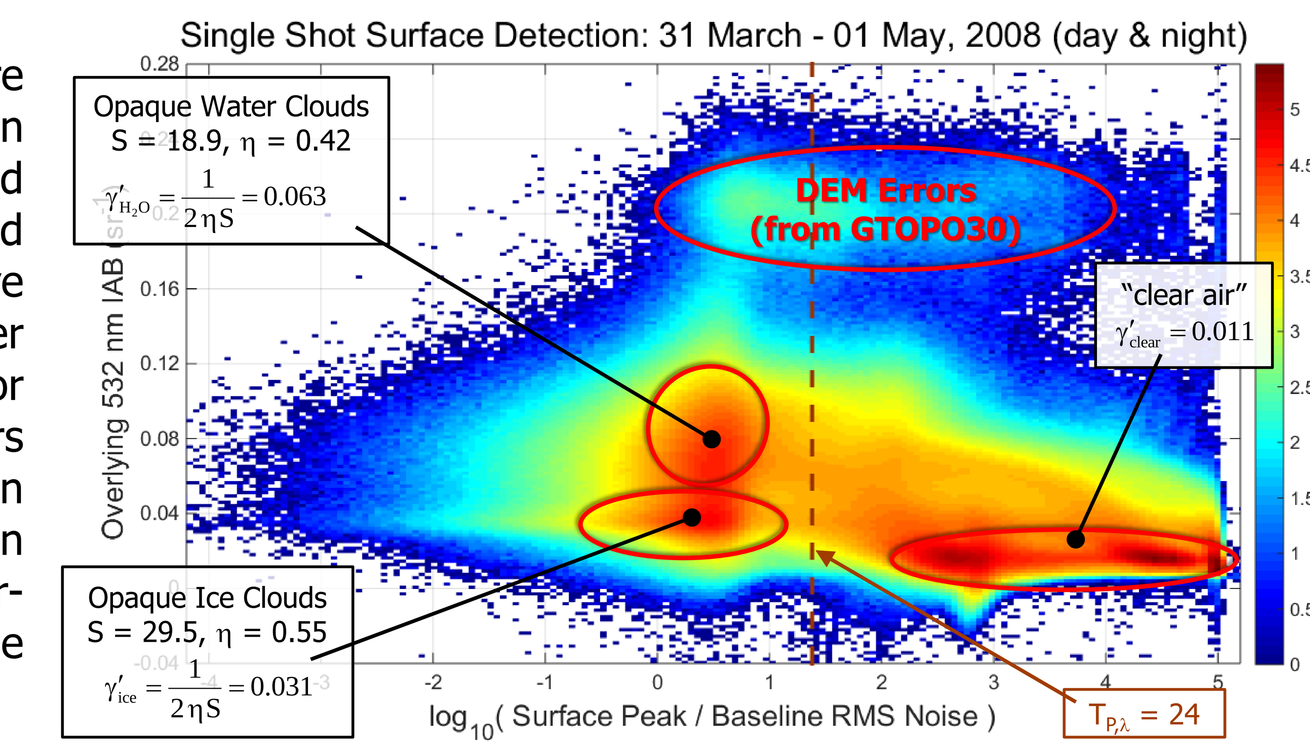
**Test 1** : is the minimum derivative altitude higher than the maximum derivative altitude?

**Test 2** : is the peak signal greater than $T_{P,\lambda}$ times the scaled RMS background, where $T_{P,\lambda}$ is a configurable runtime constant (i.e., does the maximum signal rise significantly above the background noise)?

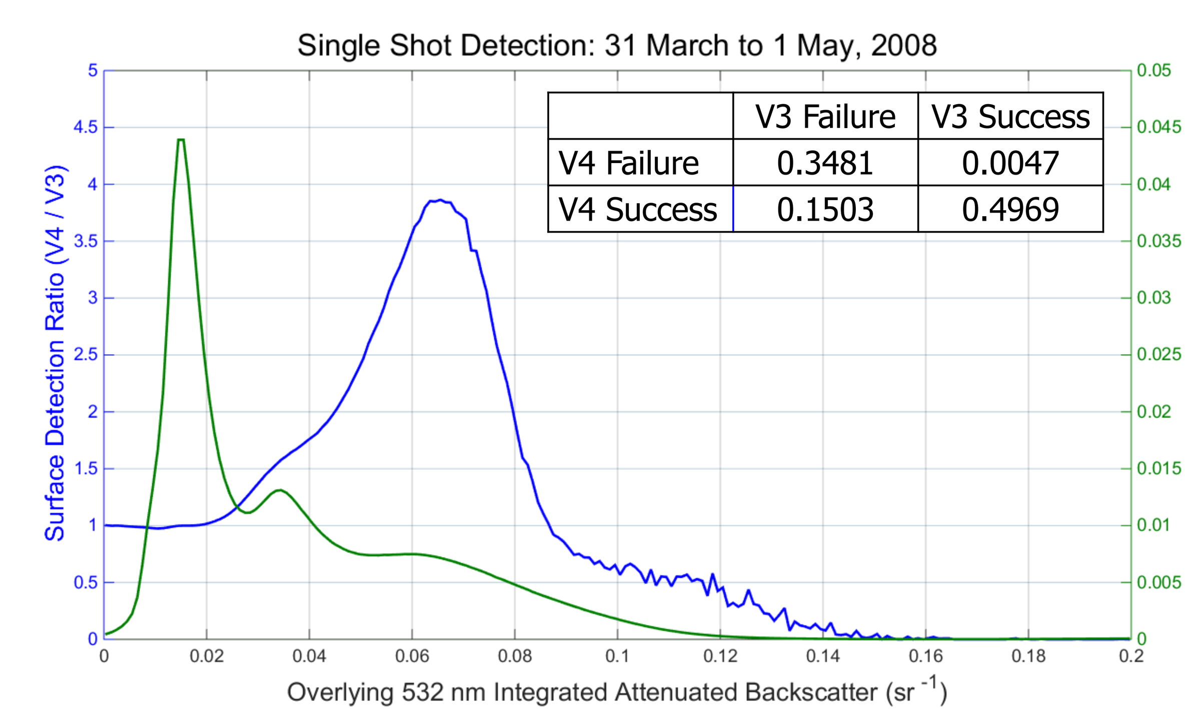
**Test 3** : is the distance between the minimum and maximum derivatives less than $N_\lambda$ range bins?

**Test 4** : are the minimum derivative altitudes at 532 nm and 1064 nm within 2 or fewer ranges bins of each other?

**Test 2: Thresholding** The figure to the right illustrates the relation between the value of $T_{P,\lambda}$ (dashed line) and the overlying integrated attenuated backscatter (γ′) above the surface. γ′ for an opaque layer depends on lidar ratio; e.g., γ′ for ice clouds and water clouds differs by a factor of 2. The attenuation of the surface peak depends on optical depth, not γ′, so the surface can be detected under a wide range of γ′ values.

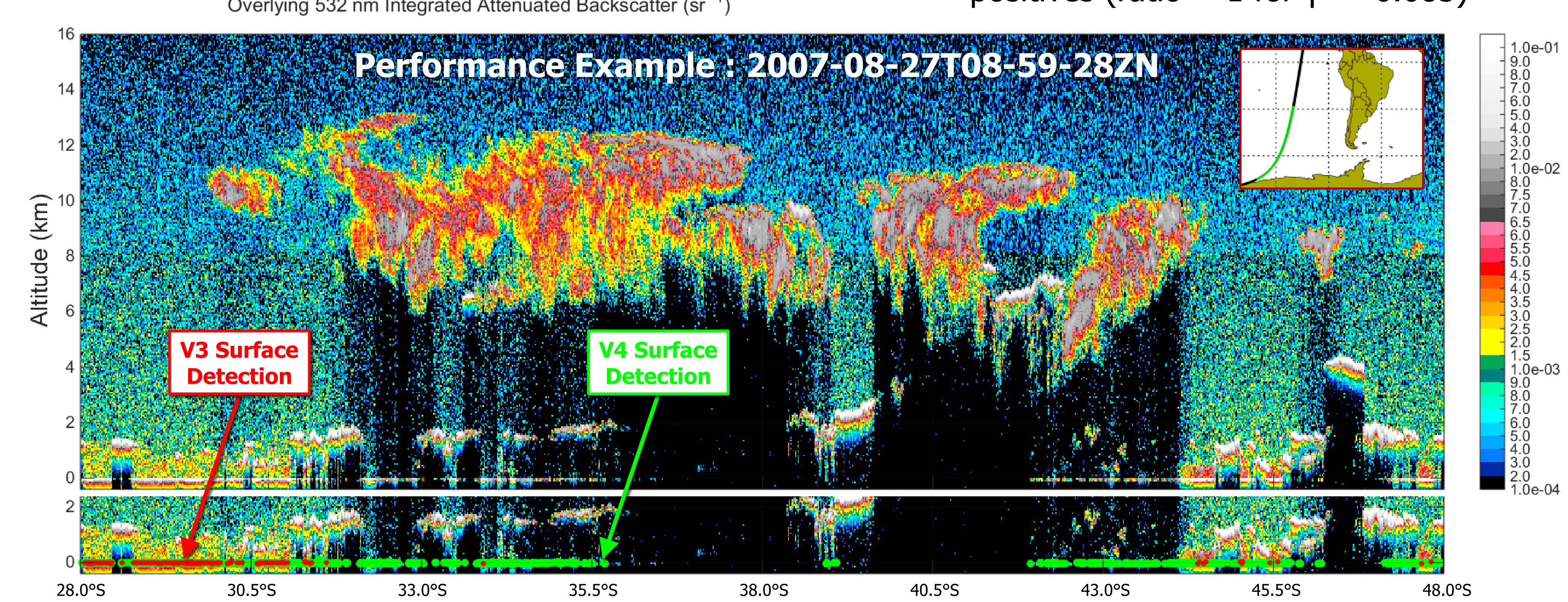



## Comparing the V4 and V3 Algorithms

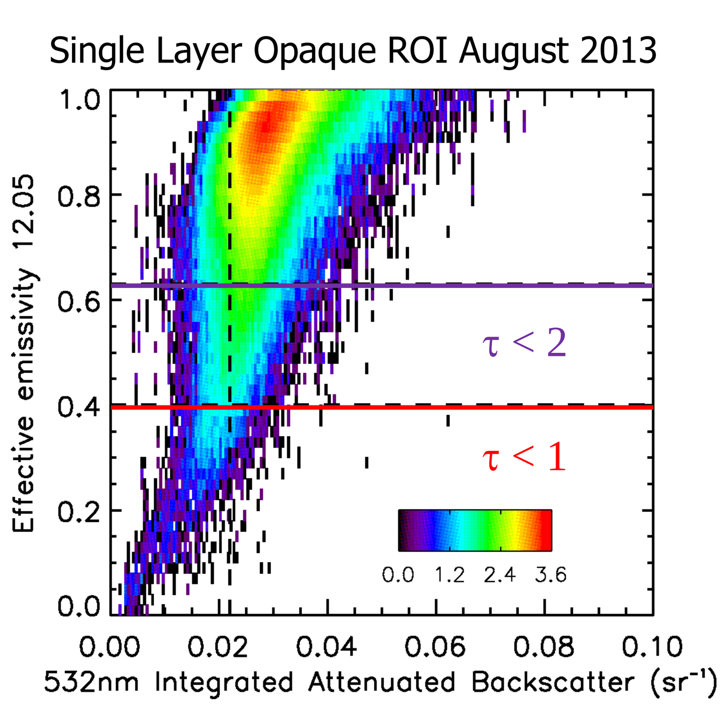



| | V3 Failure | V3 Success |
|---|---|---|
| V4 Failure | 0.3481 | 0.0047 |
| V4 Success | 0.1503 | 0.4969 |

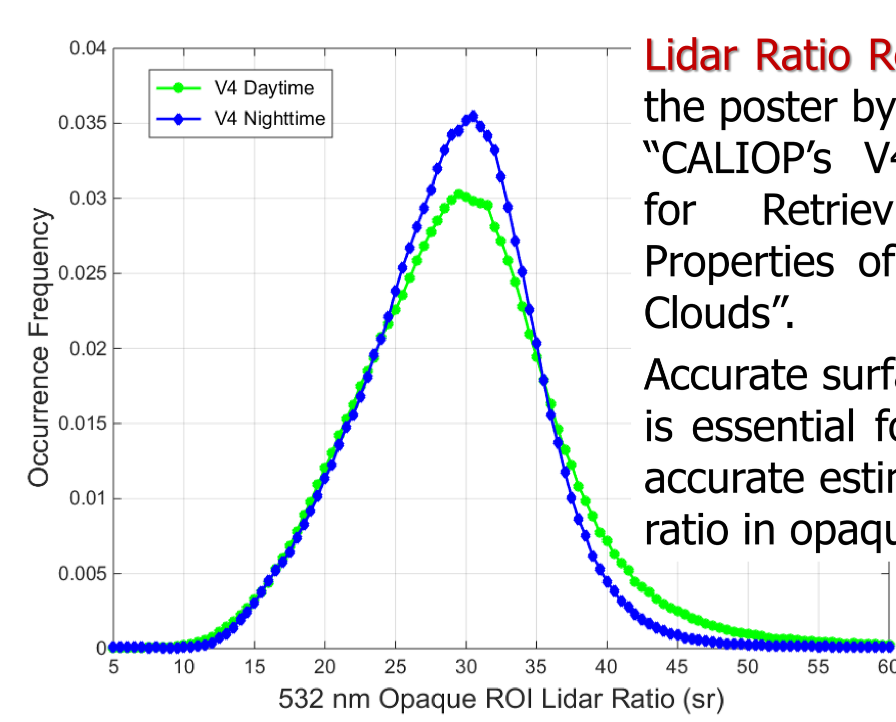
**Performance Metrics: V3 vs. V4** The blue line in the figure to the left shows the frequency of V4 surface detections relative to V3 as a function of overlying γ′. For reasonably clear skies (γ′ < 0.02 $sr^{-1}$), the V3 and V4 algorithms perform equally well, as indicated by the detection ratio of 1. However, in turbid scenes with high overlying γ′, the V4 algorithm performs substantially. Likewise, in totally opaque situations, V4 reports fewer false positives (ratio < 1 for γ′ > 0.085)




## Downstream Data Product Benefits




**IIR Error Mitigation**: the distribution of effective emissivities of V3 "opaque" cirrus with backscatter centroid altitudes above 7 km and centroid temperatures colder than -35°C shows that ~6% of the layers have effective emissivities smaller than 0.63 (a visible optical depth of ~2). For ~1% of the layers, the effective emissivity is smaller than 0.4, equivalent to an optical depth less than ~1. 7.5% of the layers have a value of γ′ smaller than 0.022 $sr^{-1}$, but only 33% of those layers exhibit effective emissivities smaller than 0.63.




**Lidar Ratio Retrievals**: see the poster by Young et al., "CALIOP's V4 Algorithms for Retrieving Optical Properties of Opaque Ice Clouds".

Accurate surface detection is essential for generating accurate estimates of lidar ratio in opaque layers.

Poster presented at the CALIPSO-CloudSat Science Team Meeting held 1-3 March 2016 in Newport News VA